METABK 55(4) 643-646 (2016)
UDC – UDK 539.374:669.15.784:536.5:620.17=111

HIGH-TEMPERATURE CHARACTERISTICS OF 20MnB4 AND 30MnB4 MICRO-ADDITION COLD UPSETTING STEELS AND C45 AND C70 HIGH-CARBON-STEELS

Received – Primljeno: 2015-12-31
Accepted – Prihvaćeno: 2016-05-05
Original Scientific Paper – Izvorni znanstveni rad

The paper analyzes the high-temperature plasticity characteristics of 20MnB4 and 30MnB4 with micro-additives, intended for cold upsetting and high-carbon steels C45 and C70 in the "solid phase-liquid" during heating and cooling. The investigation was conducted to determine the plastic formability of the examined alloy under hot plastic working conditions. Experiments were carried out on the simulator Gleeble 3800 with the aim of determining the susceptibility of 20MnB4, 30MnB4, C45 and C70 steels to cracking at high temperature. The nil strength (NST), nil ductility (NDT) and ductility recovery temperatures (DRT), and the fracture toughness factor and the BRT (brittleness temperature range) have been determined.

Key words: plasticity, alloy steel, high – carbon steel, temperature, mechanical properties

INTRODUCTION

Wire rod of 20MnB4 and 30MnB4 cold upsetting steels and C45, C70 high-carbon steels are used for the production of fasteners, such as screws, nuts, bolts, etc. Rolled products of these steels should be characterized by a homogeneous structure and consistent mechanical properties, small dimensional tolerances and good susceptibility to being formed by subsequent cold plastic working. These steels need to be easily weldable and should ensure the economical manufacture of products with complex shapes (without cracks, necking).

Investigation was carried out within this study to determine the parameters characterizing the mechanical properties, and to establish the temperature ranges for the drop of plasticity for temperature conditions corresponding to the conditions of concast slab solidification in the CSC machine, cold upsetting micro-additive 20MnB4 and 30MnB4 steels and C45, C70 high-carbon steels at high temperatures, also in the "solid phase – liquid" field, during heating and cooling [1-8], including:

– NST (nil strength temperature) – the temperature defining the transition of heated metal or alloy into the state of zero strength;
– NDT (nil ductility temperature) – the temperature at which heated metal or alloy loses completely its plasticity;
– DRT (ductility recovery temperature) – the temperature at which the plastic properties are recovered during cooling after heating.

To describe the fracture toughness of steel, R_f the parameter is introduced, which is defined as follows:

$$R_f = \frac{NST - NDT}{NDT} \tag{1}$$

This parameter is called the fracture toughness factor; the higher its value, the greater the cracking susceptibility of the steel.

The temperature span between the NST and the DRT is defined as the brittleness temperature range (BTR). The main objective of the undertaken investigation was to determine the resistance of the material to crack initiation. The tests were carried out using the Gleeble 3800 Metallurgical Process Simulator available at the Institute for Plastic Working and Safety Engineering [9-10].

TEST MATERIAL AND TESTING METHODOLOGY

Specimens of cold upsetting micro-addition steels 20MnB4 and 30MnB4 and high-carbon steels C45 and C70, whose chemical composition is given in Table 1, were used for testing. The specimens were made in conformance to the guidelines of Dynamic Systems Inc. – the manufacturer of the Gleeble 3800 simulator.

Table 1 **Chemical composition / mas. %**

Steel Grade	C	Mn	Si	P max.
C45	0,40-0,45	0,50-0,80	0,10-0,30	0,035
C70	0,68-0,73	0,50-0,80	0,10-0,30	0,035
20MnB4	0,18-0,23	0,90-1,20	max. 0,30	0,025
30MnB4	0,27-0,32	0,80-1,10	max. 0,30	0,025
Cr max.	Ni max.	Mo max.	Cu max.	S max.
0,20	0,25	0,05	0,30	0,035
0,15	0,20	0,05	0,25	0,035
0,30	-	-	0,25	0,025
max. 0,30	-	-	0,25	0,025

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METHODOLOGY FOR DETERMINING THE MATERIAL CHARACTERIZING PARAMETERS

In determining the NST, two tests are initially performed. If the difference between the obtained NST values is > 20 °C, then a third test will need to be performed. The mean value is the NST temperature. Specimens for NST determination were heated initially at a heating rate of 20 °C/s up to a temperature of 1 250 °C, and at a heating rate of 1 °C/s up to the rupture temperature. The NST was determined based on 5 tests for each of the materials investigated.

The determined NST was 1 415 °C for steel 20MnB4, 1 418 °C for steel 30MnB4 and 1 400 °C for steel C45 and 1 373 °C for steel C70.

Specimens for NDT determination were heated initially at a heating rate of 20 °C/s up to a temperature of 1 250 °C, and at a heating rate of 1 °C/s up to the deformation temperature. Next, the specimen was held for 5 second for the temperature to stabilize, and then tensioned at a ram advance speed of 1 mm/s and 20 mm/s, respectively. An example NDT test is illustrated in Figure 1.

The variation of the reduction of area as a function of deformation temperature is represented in Figures 2 – 5.

It can be found from the diagram in Figure 2 that the NDT for steel 20MnB4 is 1 390 °C for the ram advance speed of 1 mm/s and 1 400 °C for the ram advance speed of 20 mm/s, for steel 30MnB4 is 1 380 °C for the ram advance speed of 1 mm/s and 1 400 °C for the ram advance speed of 20 mm/s (Figure 3). The NDT for steel C45 is 1 350 °C for the ram advance speed of 1 mm/s and 1 375 °C for the ram advance speed of 20 mm/s (Figure 4), for steel C70 is 1 340 °C for the ram advance speed of 1 mm/s and 1 290 °C for the ram advance speed of 20 mm/s (Figure 5).

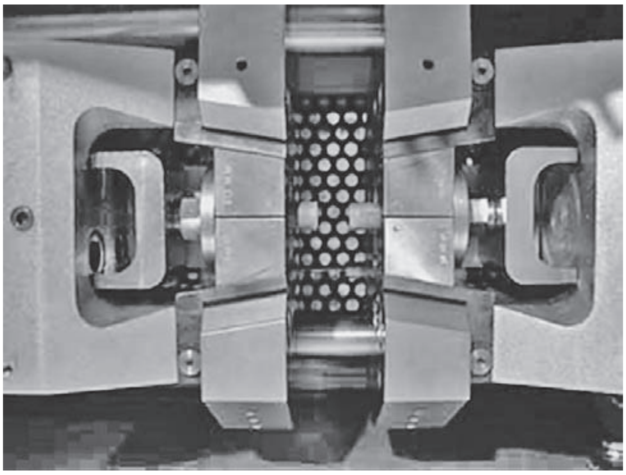

Figure 1 An example NDT test

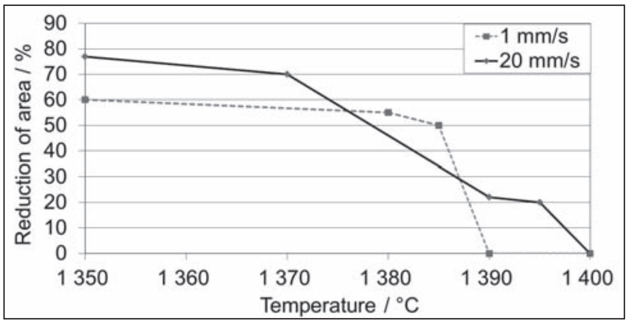

Figure 2 Diagram of the variation of ductility during NDT determination for steel 20MnB4

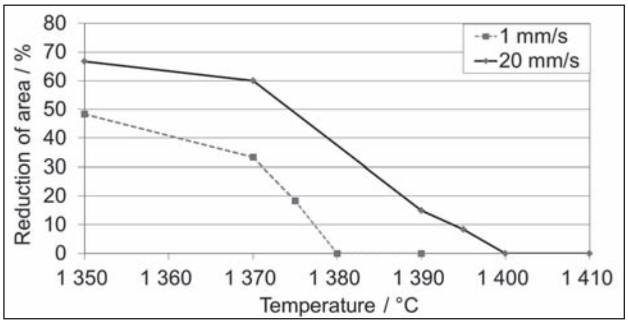

Figure 3 Diagram of the variation of ductility during NDT determination for steel 30MnB4

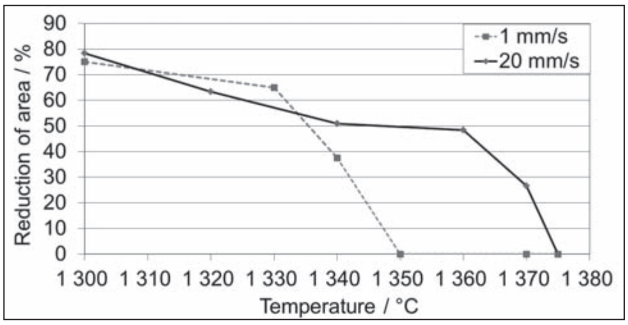

Figure 4 Diagram of the variation of ductility during NDT determination for steel C45

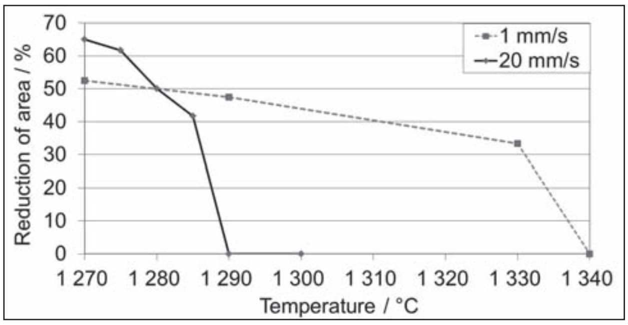

Figure 5 Diagram of the variation of ductility during NDT determination for steel C70

The DRT was determined by heating specimens up to a temperature of 1 250 °C/s at a heating rate of 20 °C/s, and then at a heating rate 1 °C/s to the NST, that is 1 415 °C for steel 20MnB4, 1 418 °C for steel 30MnB4, 1 400 °C for steel C45, 1 373 °C for steel C70. After 5-second temperature equalizing, the specimens were cooled down to the deformation temperature. The cooling rate was 1 °C/s. The deformation was preceded by 5-second holding at the preset deformation temperature – the ram advance speed was 1 mm/s and 20 mm/s, respectively. The value of the DRT was determined after 5 % of the reduction of area had been recovered. The variation of the reduction of area as a function of deformation temperature is represented in Figures 6 ÷ 9.

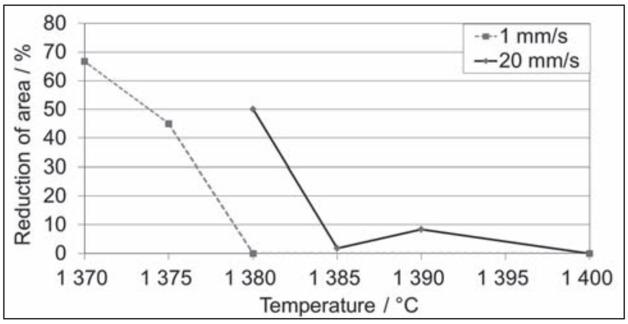

Figure 6 Diagram of the variation of ductility during DRT determination for steel 20MnB4

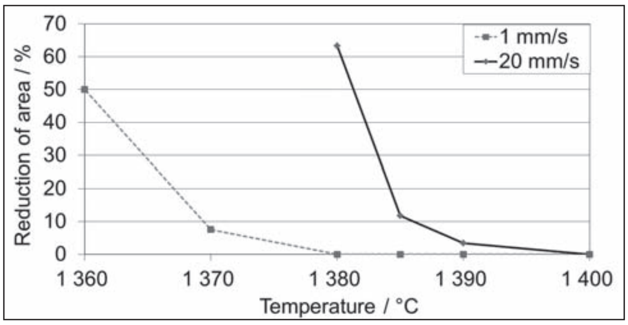

Figure 7 Diagram of the variation of ductility during DRT determination for steel 30MnB4

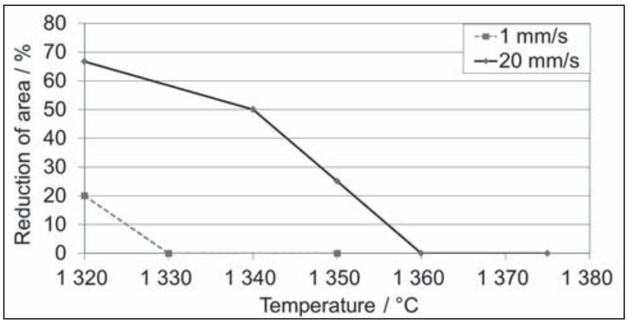

Figure 8 Diagram of the variation of ductility during DRT determination for steel C45

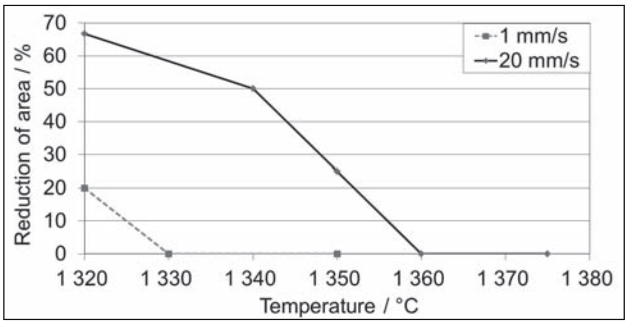

Figure 9 Diagram of the variation of ductility during DRT determination for steel C70

It can be found from the diagram in Figure 6 that the DRT for steel 20MnB4 is 1 379 °C for the ram advance speed of 1 mm/s and 1 384 °C for the ram advance speed of 20 mm/s, for steel 30MnB4 is 1 373 °C for the ram advance speed of 1 mm/s and 1 388 °C for the ram advance speed of 20 mm/s (Figure 7). The DRT for steel C45 is 1 328 °C for the ram advance speed of 1 mm/s and 1 358 °C for the ram advance speed of 20 mm/s (Figure 8), for steel C70 is 1 327 °C for the ram advance speed of 1 mm/s and 1 358 °C for the ram advance speed of 20 mm/s.

The obtained results were used for determining the fracture toughness factor, R_F, for the tested materials – the higher the R_F value, the greater the cracking susceptibility of the material.

The fracture toughness factor, R_f, for steel 20MnB4:

$$1\ mm / s \rightarrow R_f = 0{,}01798$$
$$20\ mm / s \rightarrow R_f = 0{,}01071$$

The fracture toughness factor, R_f, for steel 30MnB4:

$$1\ mm / s \rightarrow R_f = 0{,}02753$$
$$20\ mm / s \rightarrow R_f = 0{,}01285$$

The fracture toughness factor, R_f, for steel C45:

$$1\ mm / s \rightarrow R_f = 0{,}03740$$
$$20\ mm / s \rightarrow R_f = 0{,}01818$$

The fracture toughness factor, R_f, for steel C70:

$$1\ mm / s \rightarrow R_f = 0{,}02462$$
$$20\ mm / s \rightarrow R_f = 0{,}06434$$

The temperature span between the NST and the DRT is defined at the BTR. For steel 20MnB4, BTR was, respectively, ~ 36 °C (at 1 mm/s) or ~ 31 °C (at 20 mm/s). For steel 30MnB4, on the other hand, the BTR was, respectively, ~ 45 °C (at 1 mm/s) or ~ 30 °C (at 20 mm/s). For steel C45, the BTR was, respectively, ~ 72 °C (at 1 mm/s) or ~ 42 °C (at 20 mm/s). For steel C70, on the other hand, the BTR was, respectively, ~ 46 °C (at 1 mm/s) or ~ 15 °C (at 20 mm/s).

SUMMARY

The performed investigation has enabled the determination of the high-temperature parameters of steels with micro-additives in grades 20MnB4 and 30MnB4 intended for cold upsetting and C45 and C70 high-carbon steels. The nil strength and nil ductility temperatures have been established, and the ductility recovery temperature and the values of the parameters characterizing material cracking at temperatures close to the solidus–liquidus temperature have been determined.

From the investigation, it has been found that:

- The value of the NST for steel 20MnB4 is 1 415 °C, for steel 30MnB4 – 1 418 °C, for steel C45 – 1 400 °C while for steel C70 – 1 373 °C.
- The value of the NDT for steel 20MnB4 is 1 390 °C for a ram advance speed of 1 mm/s and 1 400 °C for a ram advance speed of 20 mm/s, while for steel 30MnB4 it is equal to 1 380 °C for a ram advance speed of 1 mm/s and 1 400 °C for a ram advance speed of 20 mm/s. For steel C45 is 1 350 °C for a ram advance speed of 1 mm/s and 1 375 °C for a ram advance speed of 20 mm/s, while for steel C70 it is equal to 1 340 °C for a ram advance speed of 1 mm/s and 1 290 °C for a ram advance speed of 20 mm/s.
- The value of the DRT for steel 20MnB4 is 1 379 °C for a ram advance speed of 1 mm/s and 1 384 °C for a ram advance speed of 20 mm/s, while for steel 30MnB4 it is equal to 1 373 °C for a ram advance

speed of 1 mm/s and 1 388 °C for a ram advance speed of 20 mm/s. For steel C45 is 1 328 °C for a ram advance speed of 1 mm/s and 1 358 °C for a ram advance speed of 20 mm/s, while for steel C70 it is equal to 1 327 °C for a ram advance speed of 1 mm/s and 1 358 °C for a ram advance speed of 20 mm/s.

– The value of the parameter R_f, characterizing the resisting of steel to the cracking process is 0,01798 steel 20MnB4 for a ram advance speed of 1 mm/s and 0,01071 for a ram advance speed of 20 mm/s. For steel 30MnB4, this value equals 0,02753 for a ram advance speed of 1 mm/s and 0,01285 for a ram advance speed of 20 mm/s. For steel C45, this value equals 0,03704 for a ram advance speed of 1 mm/s and 0,01818 for a ram advance speed of 20 mm/s. For steel C70, this value equals 0,02462 for a ram advance speed of 1 mm/s and 0,06434 for a ram advance speed of 20 mm/s.
– The BTR is, respectively, ~ 36 °C (at 1 mm/s) or ~ 31 °C (at 20 mm/s) for steel 20MnB4, while for steel 30MnB4, respectively, ~ 45 °C (at 1 mm/s) or ~ 30 °C (at 20 mm/s). For steel C45, respectively, ~ 72 °C (at 1 mm/s) or ~ 42 °C (at 20 mm/s), while for steel C70, respectively, ~ 46 °C (at 1 mm/s) or ~ 15 °C (at 20 mm/s).

Acknowledgement

This scientific study was financed from the resources of the National Research and Development Centre in the years 2013÷2016 as Applied Research Project No. PBS2/A5/0/2013.

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Note: The person responsible for the English translation is Czesław Grochowina, Studio Tekst, Czestochowa, Poland